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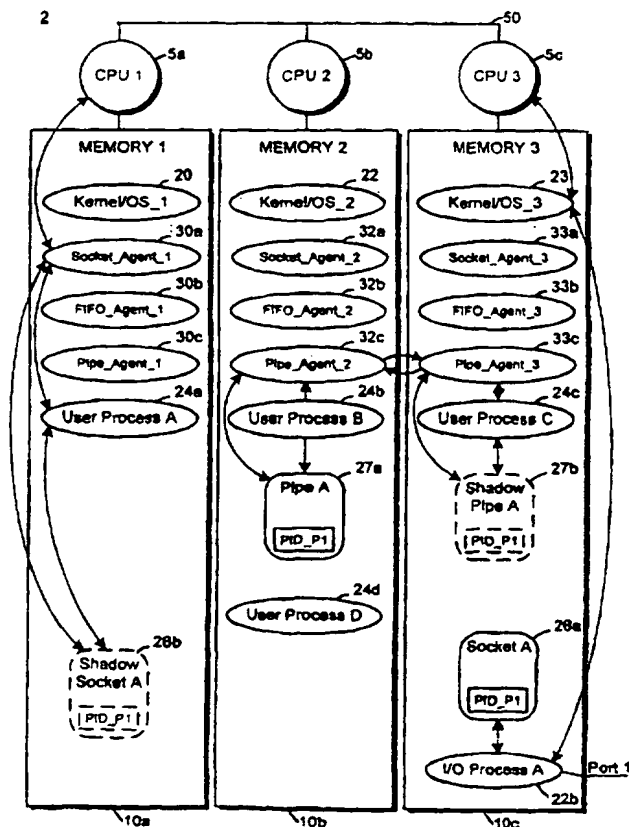
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(54) Title: INTERPROCESS COMMUNICATION IN A DISTRIBUTED COMPUTER ENVIRONMENT

(57) Abstract

A computing environment (2) includes multiple CPUs (5a-c), multiple nonshared memory spaces and a means for implementing a select system call (10a-c). The connection maintenance system is both fault-tolerant and scalable in that agents (30-33a-c) exist independently in each nonshared memory space to handle interprocess connections between memory spaces.



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## INTERPROCESS COMMUNICATION IN A DISTRIBUTED COMPUTER ENVIRONMENT

## MICROFICHE APPENDIX AND COPYRIGHT NOTICE

10           This application is being filed with a microfiche appendix consisting of 111 frames on 2 sheets containing source code listings for software components related to the invention. Appendix sections are labeled A, B, D, and E.

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## BACKGROUND OF THE INVENTION

          The present invention is related to the field of digital circuits and to the field of instructions and program code for the operation thereof. More particularly, the present invention is related to data communication between digital circuits or between processes running on the same circuit. The invention is further related to fault-tolerant and scalable distributed processor and distributed memory digital processing systems.

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          This discussion of the present invention presupposes some familiarity with computer programming and software, particularly data input and output (I/O), network communications, and interprocess communications. The present invention also presupposes some familiarity with multiprocessor and nonshared memory computer systems, as discussed in co-assigned U.S. Patent 4,228,496, which is

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incorporated herein by reference to the extent necessary to understand and enable the invention. This discussion of the present invention also presupposes some familiarity with the UNIX and related operating systems and with the well-known sockets protocol for enabling interprocess and network communication.

In all cases, the glossary and specific examples given herein are intended to be illustrative of the invention but not limiting. It will be apparent to anyone of skill in the art that the present invention may be implemented in an unlimited variety of operating system environments. Therefore, the invention should not be limited except as provided in the attached claims.

#### Background of Select() and Sockets()

In UNIX and other operating systems (OS's), processes use a `select()` (or a similar) system call to inform the OS kernel that they are interested in a particular resource for interprocess communication. A simple example would be a process that needs to wait for a particular resource to have data to read or to be available for a write. Rather than the process using CPU time to repeatedly query the connection to determine if the connection is ready, the process may call `select()` and then become dormant if the connection is not immediately ready. The call to `select()` registers with the OS kernel that the calling process needs to be awakened when the interprocess communication resource becomes ready.

The `select()` OS call may be used by a process having open connections to one or more sockets. A socket is a resource for interprocess communication that is generally used between a user process and a special I/O process handling a network I/O protocol such as the common internet protocols TCP or IP. Sockets are generally implemented as a data structure within the OS memory space, and this memory space is accessible to the OS, the I/O process responsible for delivering data to the socket, and the user process that is communicating via the socket. A socket data structure has

associated with it all state information necessary to handle the interprocess communication and generally includes a pointer to a memory location for temporarily storing the actual data packets flowing between the user process and the I/O connection.

Select() also may be used on other OS data structures used for interprocess communication such as pipes or FIFOs and for other opened I/O such as ttys, disk opens, and directory opens. While select() performs a similar function no matter what type of data structure it is called on, the details of the select() implementation for different data structures may vary in different operating systems as described more fully below.

A good description of the select() system call and sockets can be found in the reference book UNIX Network Programming, by Richard Stevens, (section 6.13), Prentice Hall, 1990.

#### Background of Distributed Memory Environments

In operating systems that have a single central processing unit (CPU) or multiple CPUs with shared memory, select() can be easily implemented because the data structures representing sockets, pipes, or FIFOs in the system are contained in a single memory space, as shown in Fig. 1, and therefore can be directly accessible to every process running in that memory space, including the OS.

However, in non-shared memory distributed systems, such as that discussed in U.S. Patent 4,228,496, select() is more difficult to implement because the information regarding the occurrence of different events on different data structures may be contained in a memory different from that which holds the user process calling select and may not be directly accessible even to the OS local to the process that called select.

What is needed is a method for performing a select() function effectively in a distributed memory environment.

## SUMMARY OF THE INVENTION

Glossary

The following terms are used in this application in accordance with the explanations below and also in accordance with their broad meanings as understood in the art.

Connection -- a means for communicating data between processes or between a process and an I/O device, such as a socket, a RAM file, a disk file, a directory, a pipe, a FIFO, a TTY, etc.

Event -- an occurrence on a connection, such as a ready-to-read, ready-to-write, or exceptional condition.

File descriptor (FD) -- An identifier local to a user process and shared by only that process and related (child) processes for identifying a particular connection opened or created by that process.

I/O process -- An input/output process for managing data input and output on some physical resources such as a network. Also called a server process.

Kernel -- The executing operating system executable code that manages the activity of all other processes.

Message -- In a distributed CPU environment, data communicated between two or more different CPUs or memory spaces over a communications channel.

Operating System (OS) -- The kernel and other callable functions and resources available to processes.

Process -- a collection (generally a sequence) of executable program code and associated state information that can independently execute and may at any given time be either executing or dormant.

Socket -- A data construct residing in a memory that allows one process to communicate data with another process via a standard interface.

User process -- A process created to perform a user function. Also called an application.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating a computing



environment of the prior art in which a select() function may be utilized.

Fig. 2 is a block diagram illustrating a distributed computing environment embodying the invention.

5 Fig. 3 is a block diagram illustrating an agent in accordance with the invention.

Fig. 4 is a flow chart of a method of creating an interprocess connection according to the invention.

10 Fig. 5 is a flow chart of a method of accomplishing a distributed select according to the invention.

Fig. 6 is a block diagram illustrating a generalized computing system upon which the present invention may be implemented.

15 DESCRIPTION OF THE PREFERRED EMBODIMENT  
Select() and Sockets in a Single-Memory-Space Computer

Fig. 1 is a block diagram illustrating a computing environment of the prior art. This figure depicts a computer system 1, with multiple CPUs 5a-b, a shared memory space 10, I/O ports 15a-b with I/O processes 22a-c, user processes 24a-c, sockets 26a-b, and FIFO 27.

Processes shown in Fig. 1 include the operating system process 20, also referred to as the kernel, I/O processes 22a-c, and user processes 24a-c.

25 Kernel 20 is a continually running process that manages the overall operation of the operating system and resource usage by other processes. I/O processes 22a-c are each generally connected to a physical I/O interconnection such as a network connection, disk drive, or video display, and manage data communications between the physical device and other processes in the system. User processes 24a-c are user-invoked executable code that perform user functions.

30 Sockets 26a-b and FIFO 27 are data structures residing in the shared memory space that are created by a process or the kernel to facilitate interprocess communication.

35 As shown in Fig. 1, SOCKET\_B is connected between I/O process 22b and user process 24a. With SOCKET\_B connected

as such, data intended for USER\_PROCESS\_A can be received by I/O\_PROCESS\_B and stored at the memory location pointed to by SOCKET\_B even when USER\_PROCESS\_A is not available. Whenever USER\_PROCESS\_A becomes available, or is awakened by the  
5 kernel, it can read the data from SOCKET\_B, without interrupting whatever new action I/O\_PROCESS\_B is undertaking. SOCKET\_B is generally constructed so that it can receive and store a large number of data packets until a user process that wants data from the socket performs a read on that socket.  
10 For each read preformed, SOCKET\_B delivers and then discards the next packet of data in the order it was received from I/O\_PROCESS\_B.

### Select()

15 A process such as USER\_PROCESS\_A may call select() on SOCKET\_B when it wants to access SOCKET\_B, but it is not sure that SOCKET\_B is ready for the type of operation desired. The select() call alerts OS kernel 20 that USER\_PROCESS\_A wishes to be awakened when SOCKET\_B is ready to perform the requested operation.

20 Stated more generally, a process may call a select()-type function when it is waiting for one or more events to occur on one or more connections. A process may go dormant after calling select() if the event does not happen  
25 immediately. In one specific implementation of select(), as called on sockets, there are three types of events: (1) a socket is ready to have data read from it, (2) a socket is ready to have data written to it, and (3) an exceptional condition relating to a socket is pending. Generally,  
30 exceptional conditions are defined only for sockets, while read/write readiness is defined for most connections.

In a specific example, the process calling select() provides the following parameters to OS kernel 20:

35 Bitmask for read;  
Bitmask for write;  
Bitmask for exception (for sockets);  
Size of bitmask (number of bits);  
Timeout; and

A variable for the select() return value.

Bits set in a bitmask identify the connections in which the calling process is interested for that operation. If no connections of interest are ready, then the process is suspended until one of the connections becomes ready or the timeout expires. The select() system call returns a count of how many requested connections are ready (this value can be 0 if the timeout expires) and updates the bitmasks -- if a bit was set and the corresponding connection is not ready, then that bit is cleared to 0; if a bit was set and the corresponding connection is ready, then the bit is left set to 1.

#### File Descriptors (FD's)

In general, in UNIX and similar systems, information regarding connections requested by a user process are communicated between the user process and the OS using File Descriptors (FD's). FD's are generally integer identifiers that are assigned when a user process executes a particular system call to establish a connection, such as open() (on existing disk files, directories, etc.), socket(), pipe(), etc. FD's, once returned, are used for subsequent system calls like read(), write(), close(), or select() to identify the connection on which to perform the operation, and are used in bitmasks as described above. FD's in general are local to the process that requested them, but may also be inherited by child processes and in some cases may be passed to other processes. OS 20 maintains a data structure regarding information about each process, the FD's defined for that process and the connections indicated by those FD's.

#### Use of shared memory space for interprocess communication

In the shared memory system shown in Fig. 1, interprocess communication takes place through the mechanism of the shared memory and is managed by OS 20. If OS 20 or any other authorized process wishes to know the status of any one of the sockets 26a-b or of any other connection resource, it

simply reads the shared memory space where those sockets reside and thereby acquires the relevant data.

### Overview of Distributed Memory Space Implementations

5           Fig. 2 is a block diagram illustrating a computing environment 2 in which a distributed select() and other interprocess communication functions may be advantageously utilized according to the present invention. As in Fig. 1, this computer environment may include multiple CPUs 5a-c, I/O  
10 ports such as PORT\_1, user processes 24a-d, sockets such as 26a, and pipes or FIFOs such as 27a.

          Computing environment 2 differs from 1 in that environment 2 is distributed onto a number of nonshared memory spaces 10a-c, with each memory space generally having its own  
15 OS kernel 20, 22, or 23. Data structures, including resources for interprocess communication, residing in one memory space are not directly accessible to processes in a different memory space. For purposes of this discussion, data structures, processes, and CPUs will be referred to as *local* to one  
20 another if they are directly associated with the same memory space and will be referred to as *remote* to processes or CPUs connected with other memory spaces.

          According to the present invention, a user process such as USER\_PROCESS\_A is not necessarily aware that it is  
25 running in a distributed memory environment; however, the invention allows USER\_PROCESS\_A to establish an interprocess connection with any other process in the environment as though, from USER\_PROCESS\_A's perspective, all processes were running in the same memory space.

30           According to the invention, a user process, such as USER\_PROCESS\_A, may in addition call a select() type function on opened interprocess connections even when those connections are not local to the calling process.

          Computer environment 2 includes a number of  
35 mechanisms that allow this, including communication channel 50 allowing CPUs 5a-c to communicate data to each other. One mechanism for this CPU to CPU communication is a messaging

system, such as the Guardian™ messaging system described in U.S. Patent 4,228,496.

According to the present invention, computer environment 2 also includes a number of agent processes in order to facilitate interprocess communications and implement a distributed select() function. These agent processes, such as 30a-c, 32a-c, 33a-c, are created by each OS in order to manage connections over the distributed environment as described below.

#### Establishing a Remote Interprocess Connection

The present invention may be further understood by considering the method, as illustrated by Figs. 2 and 4, by which a connection between two processes is established in a distributed memory environment in accordance with the present invention. For the purposes of this example, assume that USER\_PROCESS\_A in memory space 10a wishes to establish a connection with I/O\_PROCESS\_A residing in a remote memory space 10c. USER\_PROCESS\_A is not necessarily aware that it is running in a distributed memory environment.

According to the present invention, the interprocess connection would be created as follows: USER\_PROCESS\_A calls a system function to create the connection to I/O\_PROCESS\_A (Step S2). In one specific embodiment, this system function might be a socket() call.

The system function call is received by the memory space 10a operating system, which is specifically designed to operate over a distributed environment (Step S4). The operating system alerts SOCKET\_AGENT\_1 that USER\_PROCESS\_A wishes to create a socket with I/O\_PROCESS\_A (Step S6). SOCKET\_AGENT\_1 creates a SHADOW\_SOCKET\_A local to USER\_PROCESS\_A (Step S8). Once created, this SHADOW\_SOCKET\_A, from USER\_PROCESS\_A's perspective, behaves just as a socket would in a nondistributed memory environment.

SOCKET\_AGENT\_1 then sends a message to the remote memory space 10c via CPU\_1 and the CPU bus 50 (Step S10). When this message is received at the remote memory space by I/O\_PROCESS\_A, I/O\_PROCESS\_A creates the real SOCKET\_A in its

memory space for holding connection information and storing data received on PORT\_1 (Step S12). Whenever I/O data is received by I/O\_PROCESS\_A, I/O\_PROCESS\_A checks SOCKET\_A to determine what to do with that data (Step S14).

5           If SOCKET\_A indicates that USER\_PROCESS\_A is the destination for that data, I/O\_PROCESS\_A or kernel 23 initiates a message again through the CPU to the memory space 10a alerting the memory space 10a processes to the presence of the data in SOCKET\_A (Step S16). According to one embodiment  
10 of the invention, I/O\_PROCESS\_A, like SOCKET\_AGENT\_1, is a process that is always running and is specifically aware it is in a distributed environment. According to one embodiment of the invention, one mode is defined wherein the data is immediately transmitted from SOCKET\_A to SHADOW\_SOCKET\_A and  
15 is stored there until it is read by USER\_PROCESS\_A, and an alternative mode is defined where data is held at SOCKET\_A until a read request is received from USER\_PROCESS\_A.

          When a message is received at memory space 10a, it is passed to SOCKET\_AGENT\_1, which is always running (Step  
20 S18). SOCKET\_AGENT\_1 then examines SHADOW\_SOCKET\_A to determine whether action needs to be taken in response to the message from I/O\_PROCESS\_A (Step S20). If SOCKET\_AGENT\_1 determines that USER\_PROCESS\_A is waiting to receive data, SOCKET\_AGENT\_1 can initiate a wake-up to USER\_PROCESS\_A, which  
25 can then take the appropriate action (Step S22).

#### Distributed Select()

          The present invention further enhances a distributed memory space environment by providing a means for implementing  
30 a select() system function in that environment. According to the present invention, agents such as 30a-c perform a number of key functions in implementing a distributed select(), as illustrated in Fig. 5.

          According to one embodiment of the invention, an  
35 agent is passed, by its local OS, all select() calls from any local processes that refer to remote connections (Step T2). The agent prepares messages to the remote connections which are transmitted over message bus 50 (Step T6). The agent

process receives all notify messages from the remote connections in response to events specified by the distributed select() call (Step T8).

5       The remote process or the agent managing the remote connection keeps track of which interprocess resources (or FDs) are of interest to a given user process, and which operations are of interest for a given resource, and which CPUs are interested in a given resource/operation.

10       When an I/O process or a remote agent receives a request for a notify via a select() or other call when a particular FD is ready, if the FD is not ready, the I/O process or remote agent stores information indicating that there is interest in the FD and which CPU is interested in the FD and what event is of interest (Step T10). If the FD  
15       becomes ready for the operation of interest, the I/O process sends readiness information to the requesting CPU (Step T12).

20       Although, logically speaking, the calling process (or OS kernel on behalf of the calling process) sends the message to the remote process expressing interest in a given FD, according to the invention the response from the remote process is not necessarily returned to the calling process because the calling process may have terminated or may timeout on select() then exit normally. The present invention solves this problem by having all responses to select() returned to  
25       an agent process. The agent processes are always available to receive responses and to take the appropriate action.

30       The agent process acts as a middleman between local processes calling select() and remote processes. An agent acquires the select() messages built by an OS kernel and sends them to the remote process. An agent receives select() readiness messages from the remote process. An agent posts the information from the messages to data structures such as sockets, adds FDs to the calling process' linked list of ready  
35       FDs, and wakes the calling process when a selected FD becomes ready.

Fig. 3 shows a block diagram of an agent process as an example of an embodiment of the present invention. According to the present invention, an agent process includes

a local interface for interacting with the local operating system and local processes. According to one embodiment of the invention, this local interface 130 receives all select() calls from local processes, even those which do not require  
5 any remote access. According to the present invention, when an agent determines from its select data base that a particular connection operation requires notification of a remote process, and that remote process has not already been notified, the CPU upon which the process is running desires  
10 notification of that particular connection event, agent process 30a sends a message via a remote interface 134 to a remote process running in a remote memory space.

Once agent process 30a receives any responses to requests it has sent to remote processes, it passes those  
15 responses to a distributor 136, which determines which local processes need to be notified of the response and what action, such as waking up a local process, needs to be taken. Distributor 136 then uses a local interface to communicate such responses and take appropriate action.

20 Another aspect of the current invention is that, in order to maintain consistency between socket function calls, the present invention may employ a separate shadow socket and real socket and use of a socket agent to communicate between a user process and an I/O process even when the user process and  
25 the I/O process reside within the same memory space.

In one specific embodiment of an environment incorporating the invention, there are as many as three agent processes in each distributed memory space, one handling sockets, one handling pipes, and one handling FIFOs.

30 Alternative embodiments could employ one agent process, or more than one, to handle different interprocess communication resources. For example, one agent process could handle pipes and FIFOs and a different agent process could handle sockets.

### 35 OS Kernel Code Functions in Distributed Select()

In one specific embodiment of the present invention, OS kernel code performs several functions to implement the distributed select(). The kernel accepts and validates input



parameters from processes calling select() and gathers and formats return parameter information. It marks kernel data structures to provide information needed by the local agent process. And it builds the select() messages which are sent to remote processes.

The OS kernel in one embodiment invokes the system call "WAIT" to suspend the select() calling process. The calling process is awakened by the agent if an FD becomes ready, or by the OS kernel if select() times out or is interrupted by a signal. If the calling process is awakened due to an FD becoming ready, it still needs to learn which FD of interest is ready and for which operation (read/ write/ exception). One optimization of the present invention is to provide the agent with the location of a linked list of data structures containing information regarding ready FDs. When a calling process is awakened, the OS kernel (on behalf of the calling process) will peruse this list to learn which FDs are ready. The kernel checks whether these FDs are ones the calling process is interested in. If so, the kernel updates the calling-process-provided bitmaps and returns control to the calling process. If not, the kernel suspends the calling process again and waits for FDs of interest to become ready.

#### Reducing Messages Between CPUs

A benefit of the present invention concerns how multiple instances of the same connection or FD existing on the local CPU are handled. As is known in the art, a calling process may fork() and create child processes which inherit the parent's open FDs, or the calling process may call dup() and obtain multiple FDs which refer to the same connection. In either of these cases, it is possible that select may be called such that interest is indicated for the same FD multiple times. Both parent and child may call select() on an FD independently, or a single process may call select() using multiple FDs that refer to the same open. In order to reduce message bandwidth on bus 50 and improve system performance, it is desirable to send only a single select() message to the

remote process indicating that a particular FD and event on that FD are of interest.

According to the invention, when a second select() request comes into the local OS kernel, that select is passed to the local agent process which checks against a database it maintains to determine that the remote process has already been contacted regarding that FD and therefore there is no need to send another message to the remote process (Step T6). However, the agent process records that this second select() call was made so that when the remote process sends a response indicating that the FD has become ready, the response is distributed to all calling processes that called select() and/or to multiple duplicate FDs in the same process. Not sending unnecessary duplicate select() requests to the remote process saves duplicate messages on bus 50 on both the transmit and receive end of the select.

#### Fault Tolerance

The present invention provides a mechanism for increased fault tolerance of select() functions and interprocess communication in a distributed memory environment such as shown in Fig. 2. According to this aspect of the invention, an agent process will, from time to time, check to see if remote processes to which it is maintaining connection information are still active in a remote CPU. If a remote process terminates unexpectedly, the local agent will become aware of this and will inform local processes that may be paused or asleep, waiting for action by the remote process to awaken and to take appropriate action. According to this aspect of the invention, the distributed memory system as shown in Fig. 2 is fault-tolerant in that one entire memory space and its associated CPU can fail, and the overall environment will continue to function and recover from the failure of one piece.

### Scalability

The present invention also provides a means for increased scalability in a distributed memory system such as that shown in Fig. 2. According to this aspect of the invention, any number of additional memory spaces with CPUs may be added to an integrated system, each separate space having its own set of agent processes to handle socket, FIFO, and pipe connections. The invention will work much the same way regardless of the number of additional memory space environments that are added to the system.

### Variations of Implementation for FIFOs and Pipes

According to the present invention, interprocess communications may be handled identically for different types of interprocess connections such as sockets, pipes, or FIFO. However, the invention also allows for variations in the handling of different types of interprocess connections in order to optimize performance.

As shown in Fig. 2, a separate agent process may be created in each memory space for sockets, FIFOs, and pipes. According to an embodiment of the invention, a pipe agent such as 32c may operate similarly to the socket agent previously described, with the difference being that, for a pipe connection, the pipe agent such as 32c communicates with a remote pipe agent such as 33c rather than communicating with a remote I/O process. In this case, the remote pipe agent 33c may create a shadow pipe 27b to communicate data locally with the USER\_PROCESS\_C. Pipe agent communications such as those between 32c and 33c take over the CPU system bus 50 as for sockets. Such agent to agent communications are not necessary for socket communication, because in the case of sockets, there is always a continuously running remote I/O process that can create the remote real socket and can send a receive messages on the remote end. FIFOs and pipes are not automatically associated with such a continuously running process, and so agent to agent communication is used.

However, the essential operation of the invention for sockets, pipes, and FIFOs is similar. In each case, an

operating system according to the invention facilitates interprocess communications and the select function by providing a continuously running process at both ends of a remote interprocess connection. In the case of sockets, on one end this continuously running process is the socket agent and on the other end it is the I/O process itself. The I/O process, like the agents, is specifically designed to operate in the distributed environment and is able to send and receive messages directed to the remote memory spaces.

It should be further understood that according to the present invention, a distributed select function may also be used with other types of files, including directories and disk files. These two file types are always ready for reading and writing and never ready for exceptions, so the implementation of select() for these files, even in a distributed environment, is trivial in that once select() determines the file type, the status is known.

#### Variations of Implementation for TTYs

According to another embodiment, a TTY file, also called the character file, has select implemented in the same way as select is called on sockets. According to the invention, TTY select(), similar to socket select(), relies on a central I/O process to keep the controlling data structures. However, in the case of TTY, I/O process A 22b would be a Telnet server, and is responsible for maintaining the state of the data structures that hold the state of the open TTY connections. The Telnet server is also responsible for communicating with a TTY agent process in each CPU to give back the status to the select(), and the agent process in each CPU wakes up processes waiting for TTY select indications.

#### Contention Mode and Data Forwarding Mode

The present invention, in one embodiment, may provide for two different modes by which data received by an I/O process such as 22b is transmitted to a remote memory space.

The normal case is *data forwarding mode* in which, as soon as data is received by process 22b, process 22b examines the port address of the data and looks up the ultimate address of the data in SOCKET\_A. From 26a, process 22b determines that the data is destined for process 24a on memory 10a. Process 22b then composes a message to SOCKET\_AGENT\_1, including the packet data, and sends the message over bus 50. When the message is received by SOCKET\_AGENT\_1, SOCKET\_AGENT\_1 places the packet data in the memory location specified by SHADOW\_SOCKET\_A, and then wakes up user process 24a as appropriate.

The invention also may provide a *contention mode* forwarding strategy. I/O process 22b operates in contention mode when it determines that user processes in more than one memory space are interested in reading data from a particular socket. In that case, packet data cannot be forwarded to a shadow socket, because I/O process 22b does not know what process will next do a read on the data. In contention mode, the packet data is then stored at SOCKET\_A, and a message indicating that data is ready is sent over bus 50. When a read() is invoked by a local process such as 26b, that read is forwarded by the OS to the local socket agent, which then sends a message over bus 50 to process 22b to deliver a packet of data. In this way, the sockets protocol of always delivering the next available packet to the next read request is preserved.

#### Invention on computer readable media

Fig. 6 illustrates an example of a computer system that may be used to execute software embodying aspects of the present invention. Fig. 6 shows a computer system 700 which includes a monitor 703, screen 705, cabinet 707, keyboard 709, and mouse 711. Mouse 711 may have one or more buttons such as mouse buttons 713. Cabinet 707 is shown housing a disk drive 715 for reading a CD-ROM or other type disk 717. Cabinet 707 also houses the multiple computer processors and memory spaces as shown in Fig. 2. According to one embodiment of the invention, the invention may be incorporated into operating

system software or system utility software recorded onto a medium such as disk 717 which, when loaded into an appropriate computer system causes the system to perform the described method.

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The present invention has been described with reference to specific embodiments, but other embodiments will be obvious to persons of skill in the art. In particular, method steps are grouped functionally for the purposes of understanding the invention. It will be understood by those of skill in the art, however, that various method steps could be performed in different orders or could be placed in different functional groupings without changing the essential nature of the invention. The invention, therefore, should not be limited except as provided in the attached claims.

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WHAT IS CLAIMED IS:

1           1. A method in a computing environment having multiple  
2 CPUs and multiple memory spaces for allowing a plurality of  
3 processes existing in a first memory space to receive  
4 notifications of events occurring in a second memory space  
5 comprising:

6                 creating an agent in said first memory space;

7                 directing to said agent a request for notification  
8 of one or more events at said second memory space by one of  
9 said plurality of processes at said first memory space;

10                transmitting a message representing said request to  
11 said second memory space;

12                receiving by said agent said requested notification  
13 from said second memory space; and

14                distributing said received notification to said  
15 requesting process in said first memory space.

1           2. The method according to claim 1 further comprising:

2                storing within said first memory space information  
3 indicating events for which requested notifications are  
4 outstanding;

5                comparing a new request against said stored  
6 information regarding outstanding requests; and

7                suppressing transmission of a message representing  
8 said new request to said second memory space when a request  
9 for said notification of said event is outstanding.

1           3. The method according to claim 1 wherein said  
2 requests for notification are generated by a select()  
3 function.

1           4. The method according to claim 1 wherein said  
2 requesting process may be unaware that it is running in a  
3 distributed memory space environment.

1           5. The method according to claim 1 wherein said  
2 requests for notification are received by a process in said  
3 second memory space.

1           6. The method according to claim 5 wherein said process  
2 in said second memory space is a second agent.

1           7. The method according to claim 5 wherein said process  
2 in said second memory space is a continuously running I/O  
3 process.

1           8. The method according to claim 7 wherein said  
2 continuously running process in said second memory space is  
3 specifically designed for a distributed environment.

1           9. The method according to claim 1 further comprising:  
2           creating a first data structure in said first memory  
3 space for facilitating interprocess communications; and  
4           creating a second data structure in said second  
5 memory space for facilitating interprocess communication.

1           10. The method according to claim 9 wherein said first  
2 data structure is a shadow socket, operating with respect to  
3 said plurality of processes at said first memory space  
4 according to a standardized protocol, and wherein said second  
5 data structure is a socket, operating in said second memory  
6 space according to a standardized protocol.

1           11. The method according to claim 9 wherein said first  
2 data structure is a pipe, operating with respect to said  
3 plurality of processes at said first memory space according to  
4 a standardized protocol, and said second data structure is a  
5 shadow pipe, operating in said second memory space according  
6 to a standardized protocol.

1           12. The method according to claim 9 wherein said first  
2 data structure is a FIFO, operating with respect to said  
3 plurality of processes at said first memory space according to



4 a standardized protocol, and said second data structure is a  
5 shadow FIFO, operating in said second memory space according  
6 to a standardized protocol.

1 13. The method according to claim 10 wherein data  
2 received at said socket is forwarded to said shadow socket and  
3 stored at a location indicated by said shadow socket until  
4 read by one of said plurality of processes at said first  
5 memory space.

1 14. The method according to claim 13 wherein said socket  
2 operates according to two modes, a data forwarding mode  
3 wherein data is immediately forwarded to said shadow socket  
4 and a contention mode wherein data is held at said socket  
5 until a read request is received at said socket.

1 15. A distributed operating system incorporating a  
2 distributed select function comprising:  
3 a first agent running in a first memory space;  
4 a second agent running in a second memory space;  
5 a first data structure for interprocess communication  
6 residing in said first memory space; and  
7 a second data structure for interprocess communication  
8 residing in said second memory space;  
9 wherein said first and second agents send and receive  
10 messages between said first and said second memory spaces and  
11 provide a standard select function interface to user  
12 processes.

1 16. A distributed computing environment comprising:  
2 a plurality of central processing units;  
3 a plurality of memory spaces;  
4 a communication channel for communicating messages  
5 between said plurality of central processing units;  
6 a first agent running in a first memory space;  
7 a second agent running in a second memory space;  
8 a first data structure for interprocess communication  
9 residing in said first memory space; and

10           a second data structure for interprocess communication  
11       residing in said second memory space;  
12           wherein said first and second agents send and receive  
13       messages between said first and said second memory spaces and  
14       provide a standard select function interface to user  
15       processes.

1           17. A fixed computer readable medium containing computer  
2       executable program code, which, when loaded into an  
3       appropriately configured computer system will cause the  
4       computer to perform the method of claim 1.

1           18. A fixed computer readable medium containing computer  
2       executable program code, which, when loaded into an  
3       appropriately configured computer system will cause the  
4       computer to perform the method of claim 14.

1           19. A method in a computing environment having multiple  
2       CPUs and multiple memory spaces for facilitating communication  
3       between a process existing in a first memory space and a  
4       process existing in a second memory space comprising:  
5           creating a first agent process in said first memory  
6       space;  
7           directing to said agent a request by a first process  
8       for creation of an interprocess connection to a process in a  
9       second memory space;  
10          creating a data structure in said first memory space  
11       for facilitating interprocess communication;  
12          transmitting a message representing said request  
13       from said agent to said second memory space;  
14          receiving said request at a second process in said  
15       second memory space;  
16          creating a data structure in said second memory  
17       space for facilitating interprocess communication;  
18          using said first and said second data structures to  
19       communicate data with process in the respective memory spaces;  
20       and

21                   using said agent and said second processes to  
22                   communicate data between said data structures.

1                   20. The method according to claim 19 wherein said first  
2                   process may be unaware that it is running in a distributed  
3                   memory space environment.

1                   21. The method according to claim 19 wherein said  
2                   process in said second memory space is a second agent.

1                   22. The method according to claim 19 wherein said second  
2                   process in said second memory space is a continuously running  
3                   I/O process.

1                   23. The method according to claim 2 wherein said  
2                   outstanding requests and said suppressed new request are  
3                   generated by the same process.

1                   24. The method according to claim 2 wherein said  
2                   outstanding requests and said suppressed new request are  
3                   generated by two different processes.

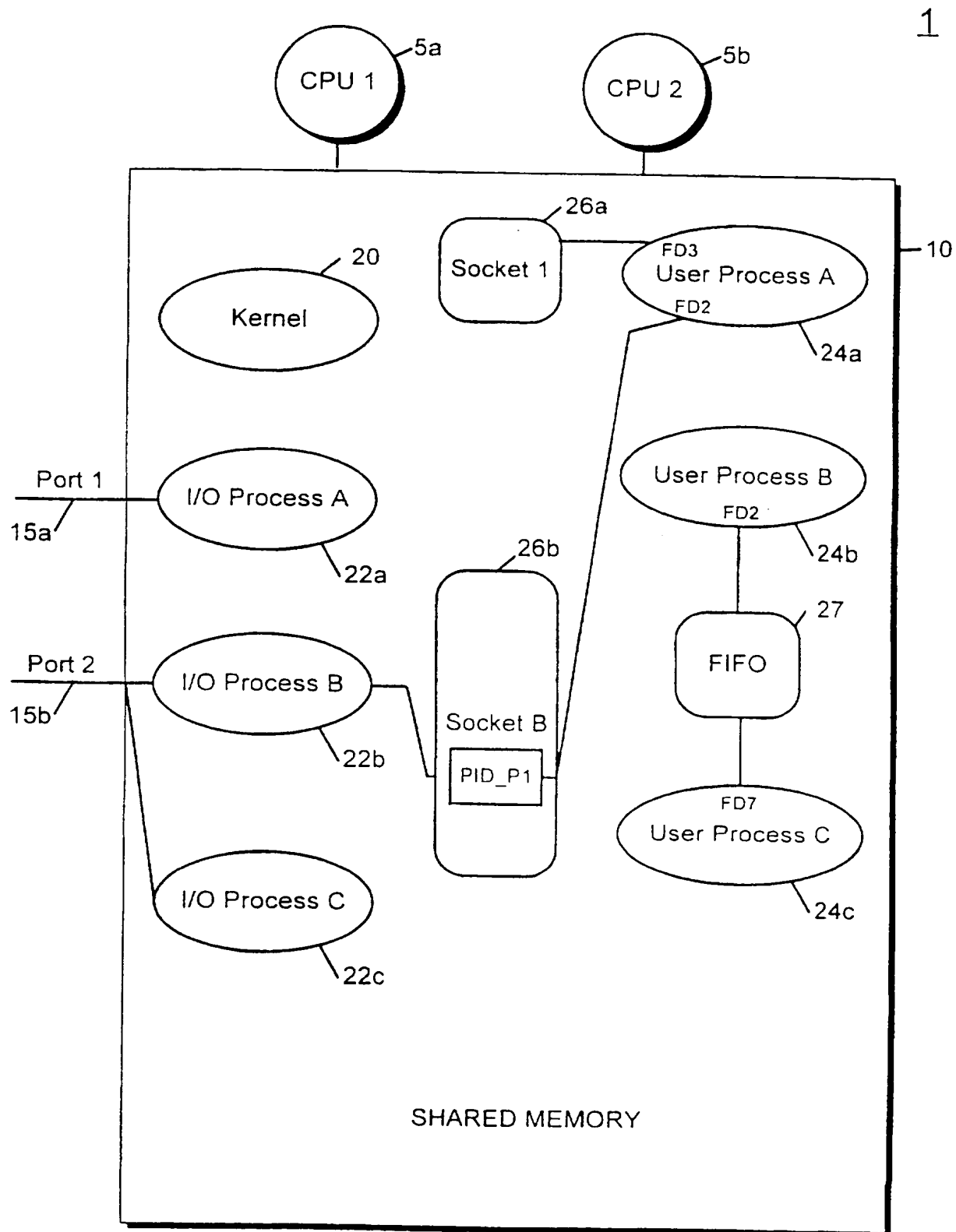


FIG. 1 (PRIOR ART)

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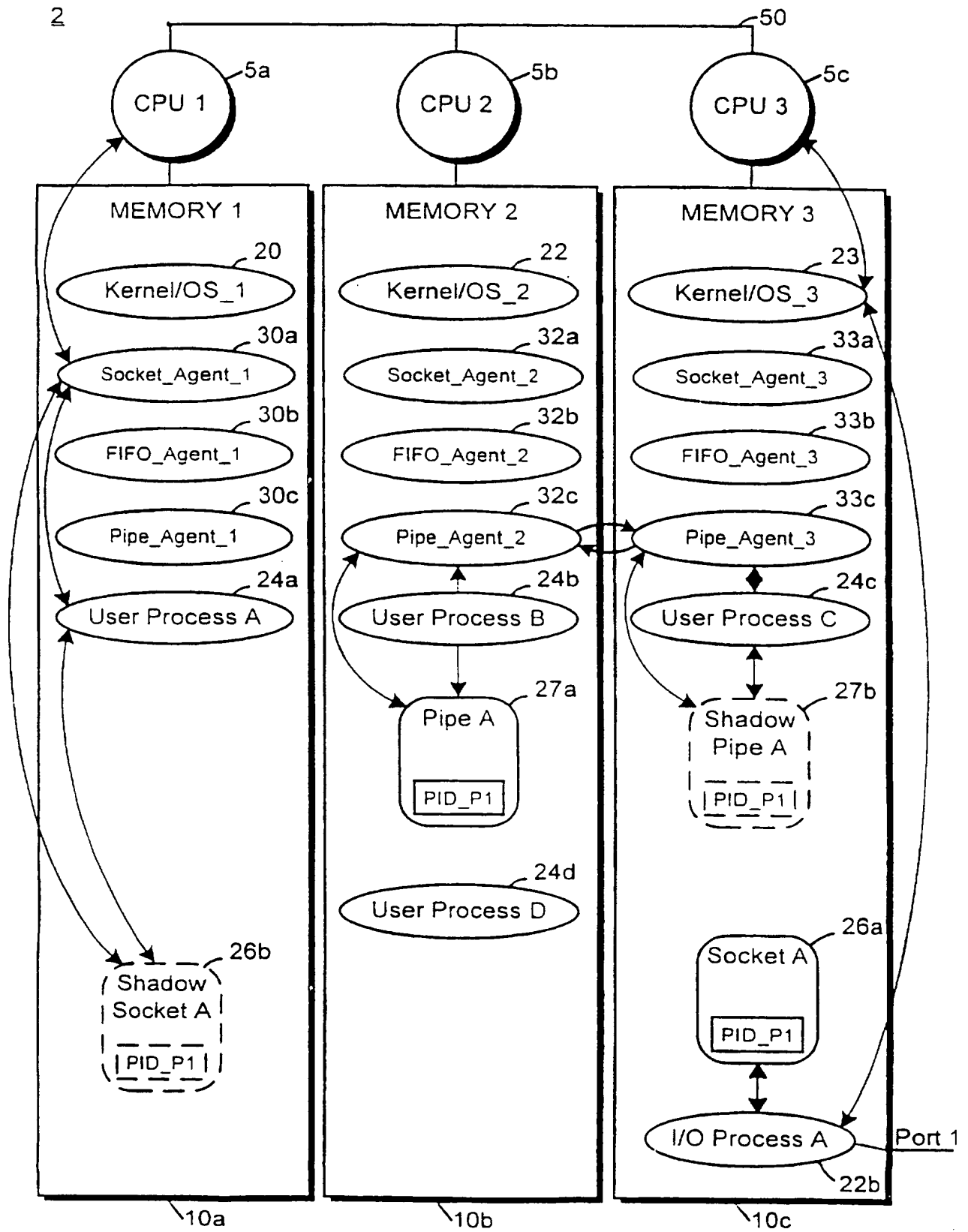


FIG. 2

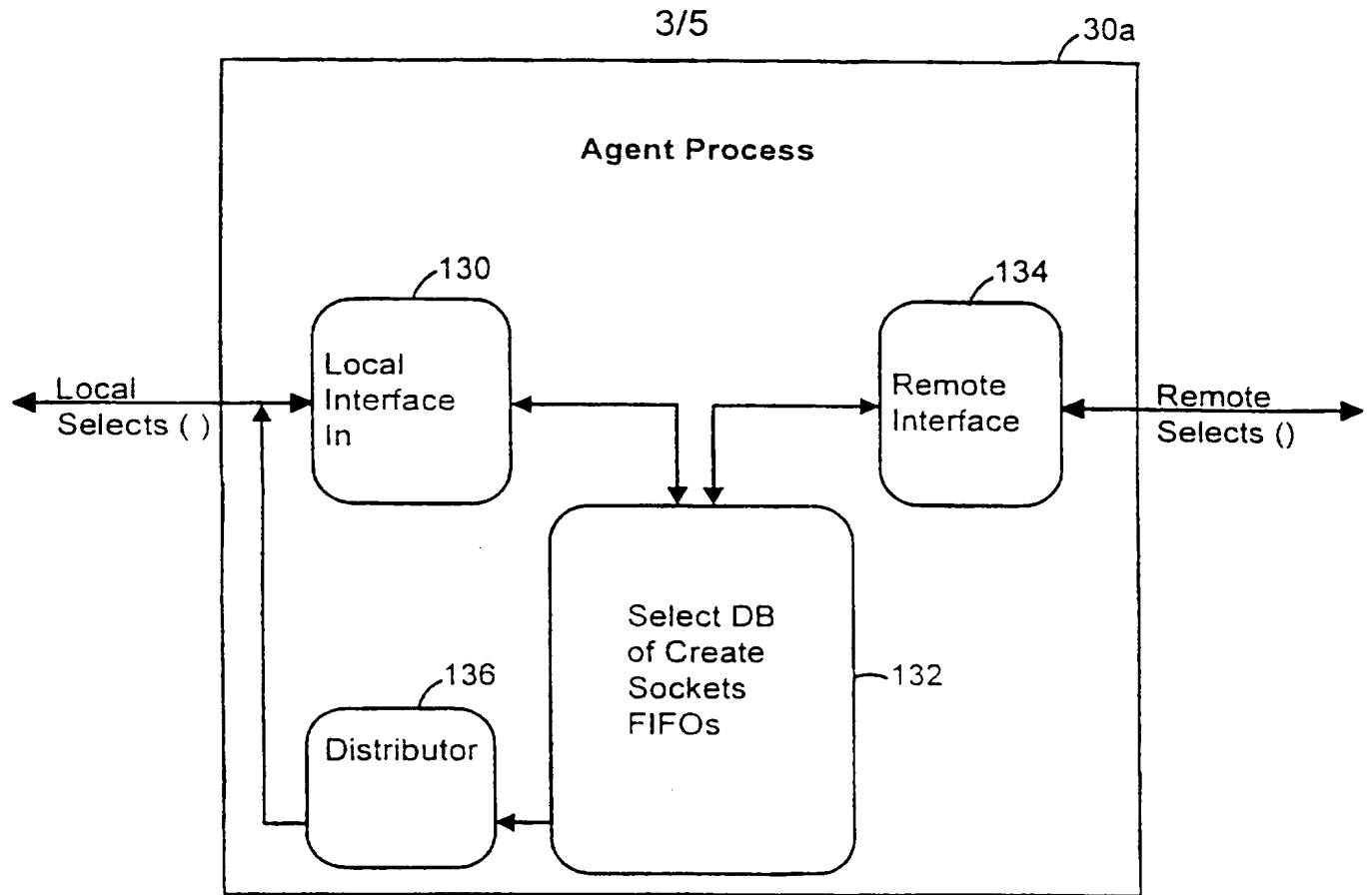


FIG. 3

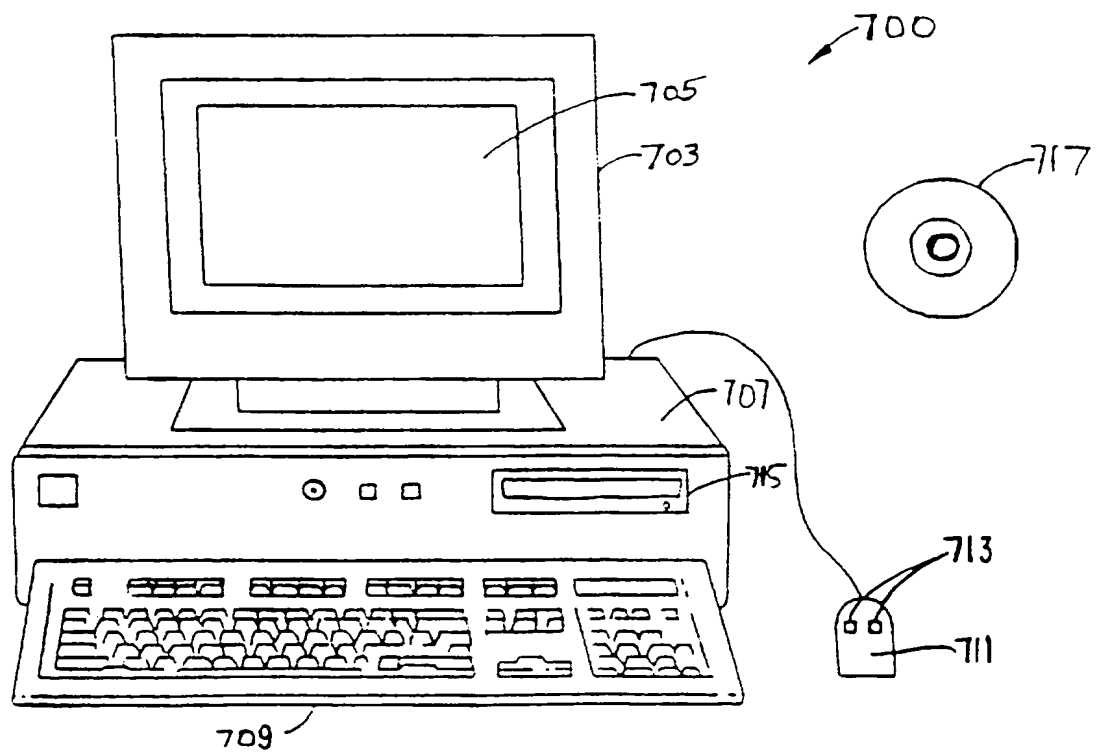


FIG. 6

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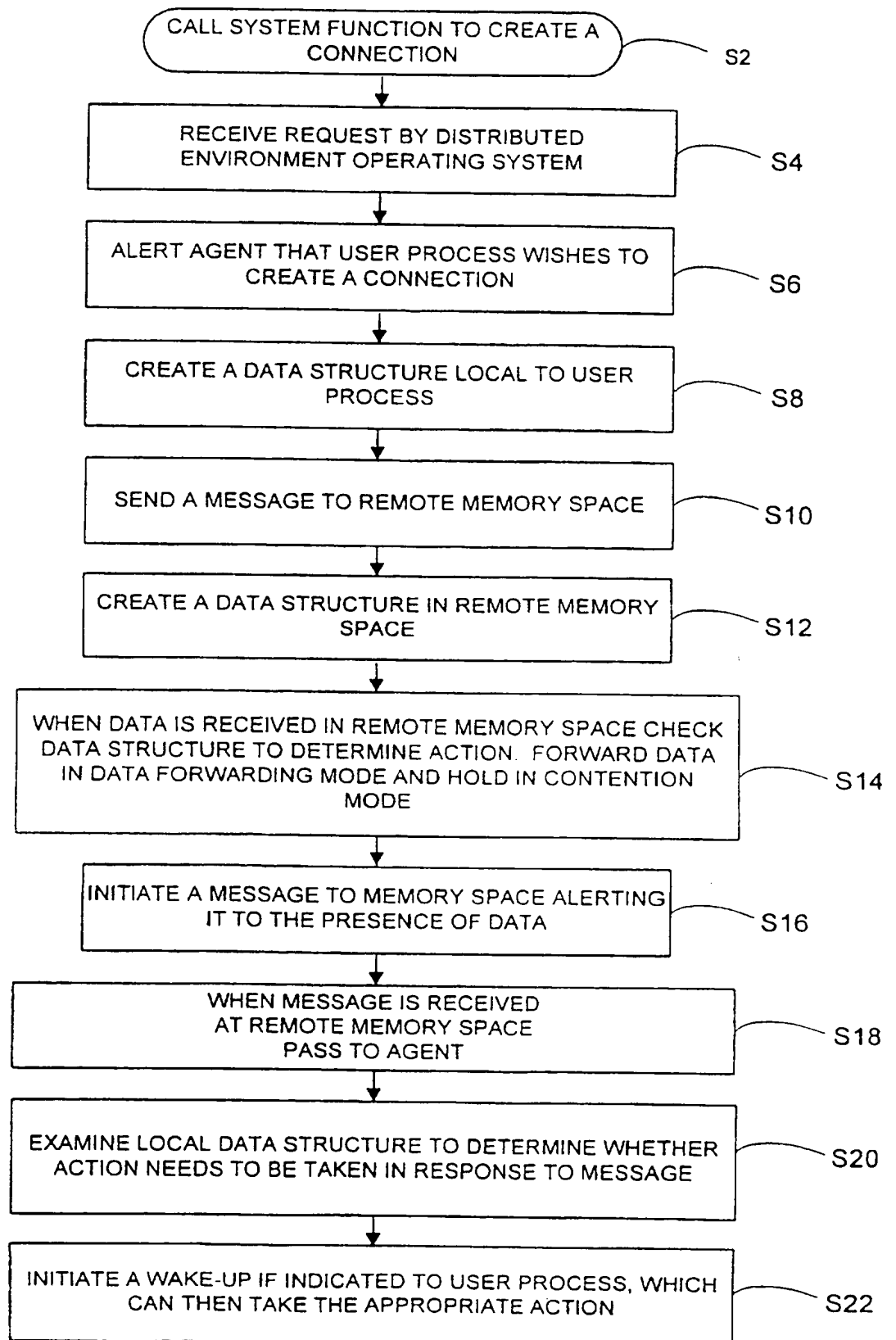


FIG. 4

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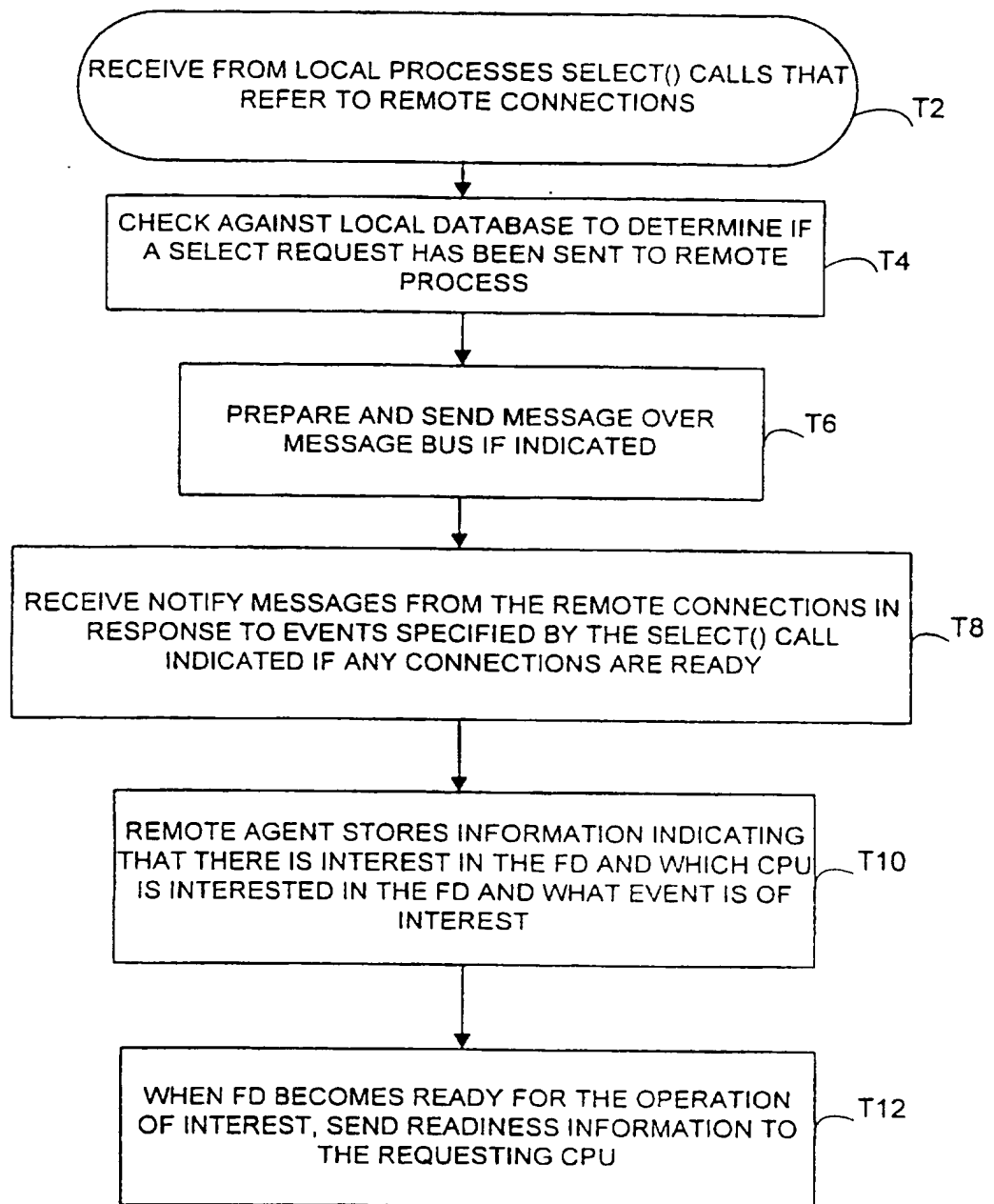


FIG. 5



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/14681

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 G06F9/46

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 723 236 A (IBM) 24 July 1996	1-9,12, 15-17, 19-24
Y	see abstract; figures 4,5 see page 5, column 11-28	10
Y	NIELSEN K ET AL: "INTER-PROCESSOR COMMUNICATION AND ADA IN DISTRIBUTED REAL-TIME SYSTEMS" COMPUTER COMMUNICATIONS, vol. 13, no. 8, 1 October 1990, pages 451-459, XP000161020 see page 452, right-hand column, line 10 - line 39; figure 2	10
A	EP 0 509 946 A (IBM) 21 October 1992 see abstract; figure 4 see column 8, line 15 - column 9, line 20	1-24

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

19 November 1997

Date of mailing of the international search report

19.12.97

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 97/14681

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 360 768 A (IBM) 28 March 1990  see page 3, line 26 - line 60; figure 1  -----</p>	1-24

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/14681

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0723236 A	24-07-96	JP 8241289 A	17-09-96
EP 0509946 A	21-10-92	CN 1065942 A	04-11-92
		JP 7306837 A	21-11-95
		KR 9514163 B	22-11-95
EP 0360768 A	28-03-90	US 4924384 A	08-05-90
		JP 2115966 A	27-04-90

Form PCT/ISA/210 (patent family annex) (July 1992)

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